Simulating Effects of High Angle of Attack on Turbofan Engine Performance

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5th Propulsion Control and Diagnostics Workshop
Ohio Aerospace Institute (OAI)
Cleveland, OH
September 16-17, 2015

Acknowledgments

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- CFD description & results
- Engine model description & implementation
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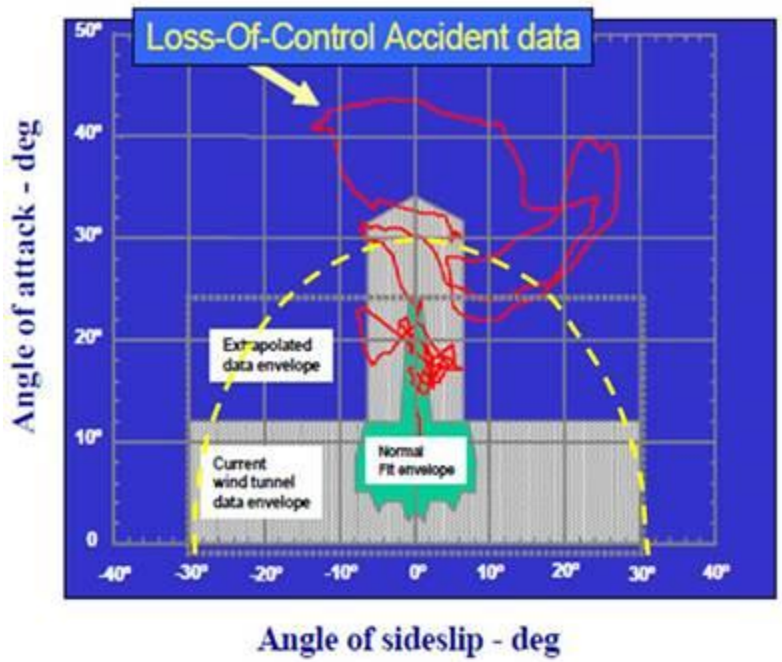
Overview

- Work initially performed under the Aviation Safety Program
- Continuing under the Airspace Operations and Safety Program

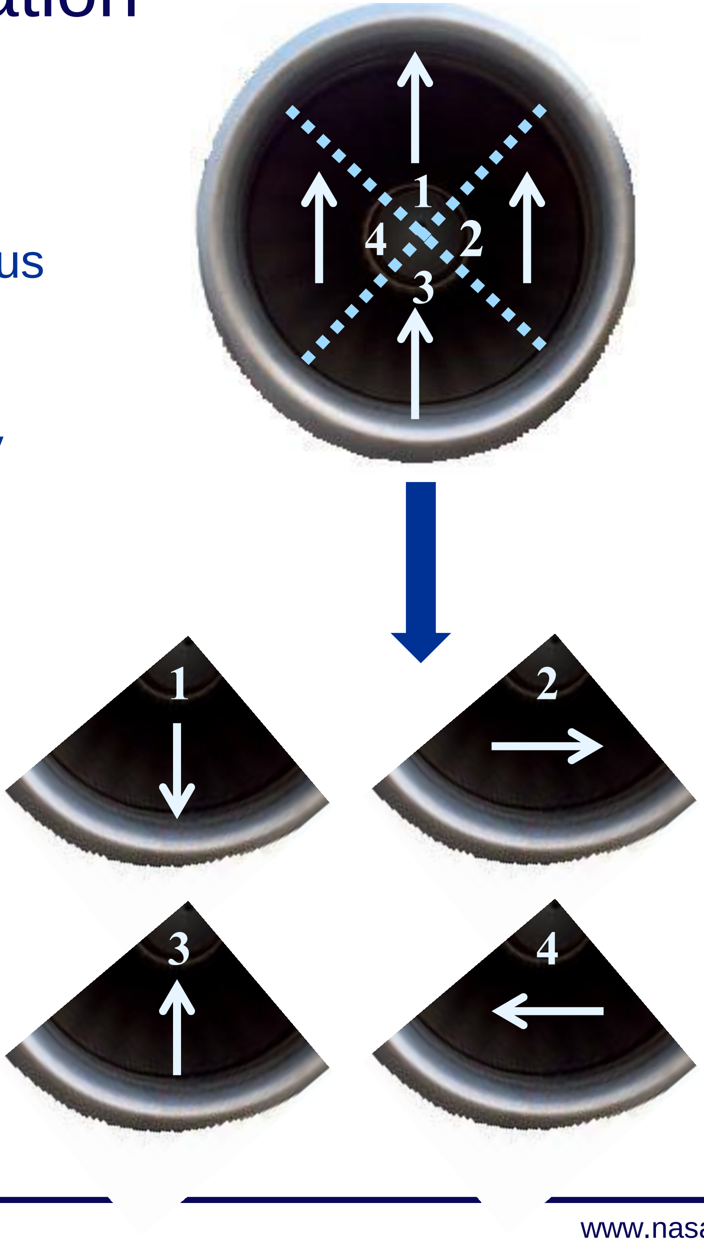


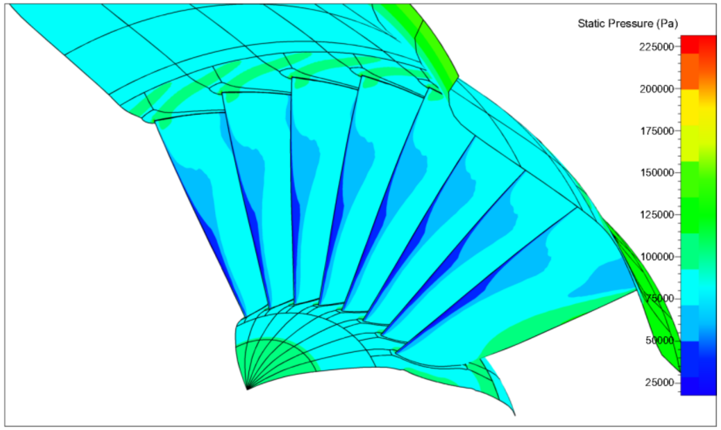
Overview

- Research into prevention and mitigation of aircraft loss-of-control scenarios
- Engine simulations generally do not account for off-nominal flight conditions, e.g. high AOA, AOSS
- Previous research efforts
  - Experimental & computational
  - High AOA: mostly military applications
  - Inlet distortion: primarily focused on compressor stability
- This work is a preliminary attempt at modeling engine-wide effects of high AOA (AOSS) operation
- Combination of two modeling efforts: 3D CFD of fan/inlet + 0D turbofan engine model

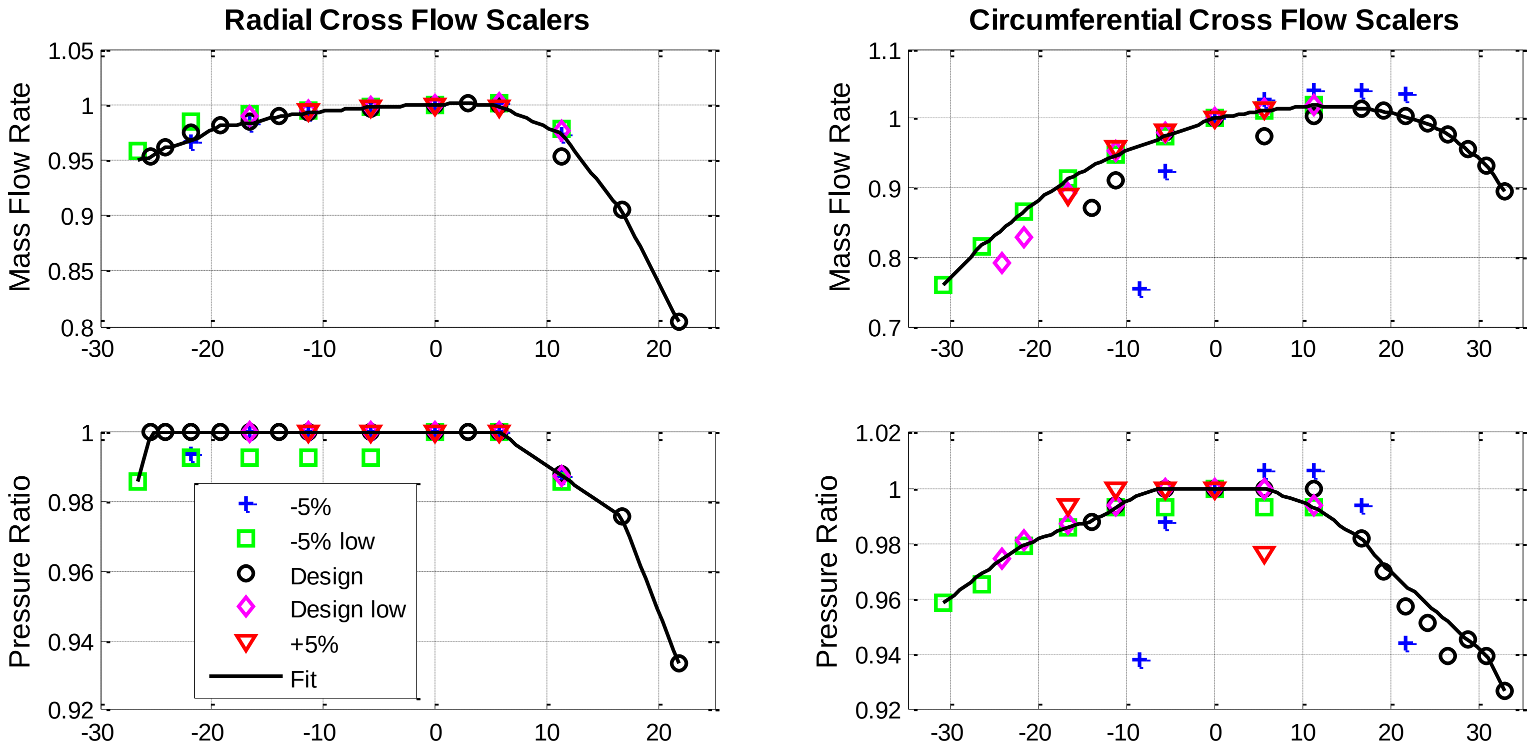
CFD Simulation

- FINE/Turbo
- E^3 fan geometry
- CFD simulation conducted on partial annulus geometry
- Given axial velocity (not shown), AOA defined by magnitude of cross-flow velocity
- Cross-flow orientation is different for each quadrant





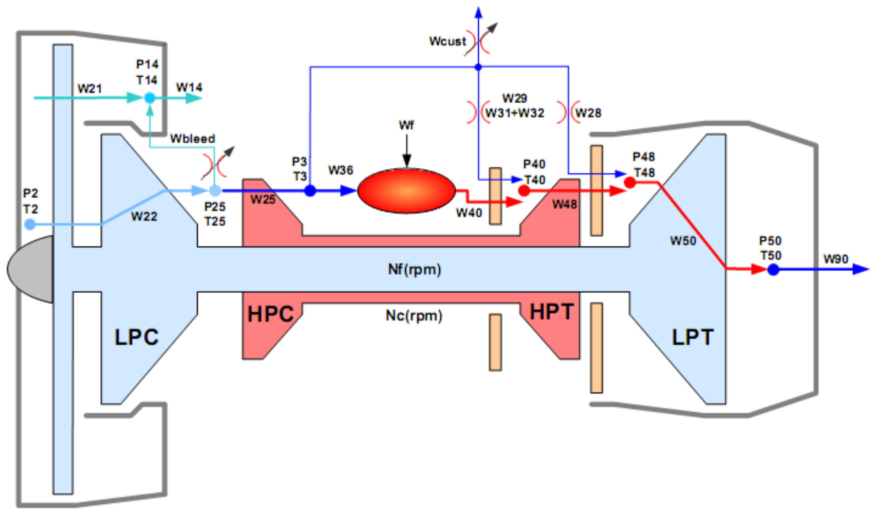
CFD Simulation: Results

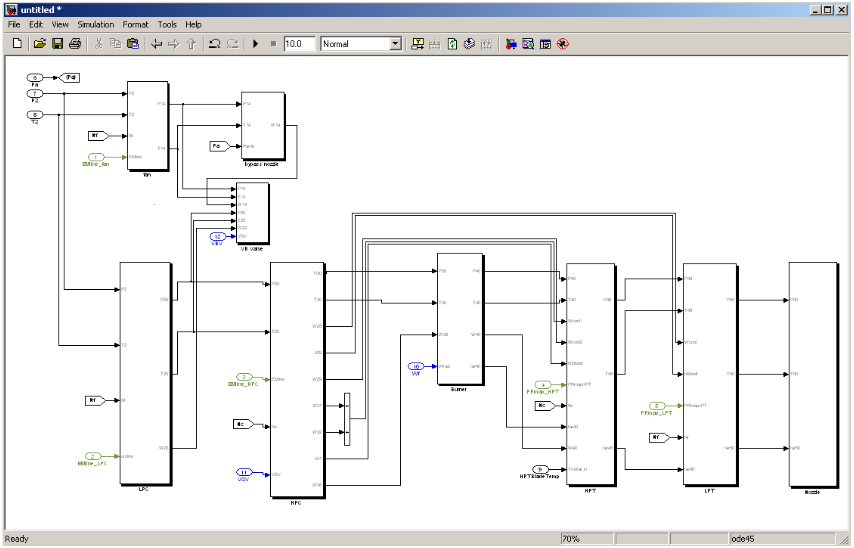


- Ran quadrant geometry through a range of cross-flow orientations (positive & negative for both circumferential & radial)
- Recorded change in W, PR, Eff as factors relative to zero cross-flow (i.e., AOA=0 condition)
- Did this for five operating points (op point defined by constant exit static pressure)

Engine Simulation: C-MAPSS40k

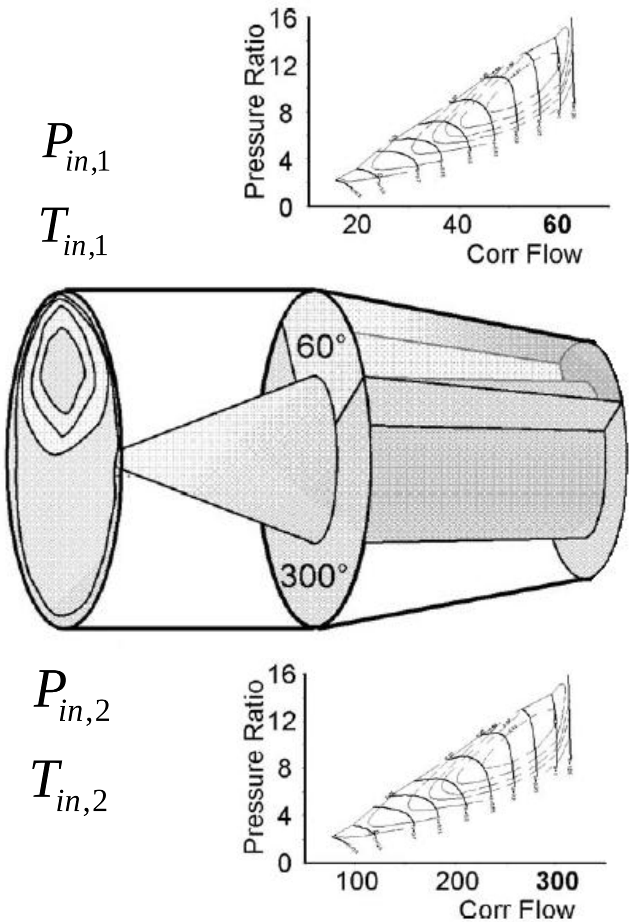
- 40,000-lb thrust class, high-bypass, dual-spool turbofan engine
- Zero-dimensional
- Spool dynamics
- Component performance maps
- Realistic control system (based on fan speed or engine pressure ratio)





Engine Simulation: Parallel Compressor

- Technique for simulating inlet distortion effects
- Multiple parallel copies of compressor model
- Inlet conditions varied to approximate desired distortion pattern



$$P_{s1} = P_{s2}$$

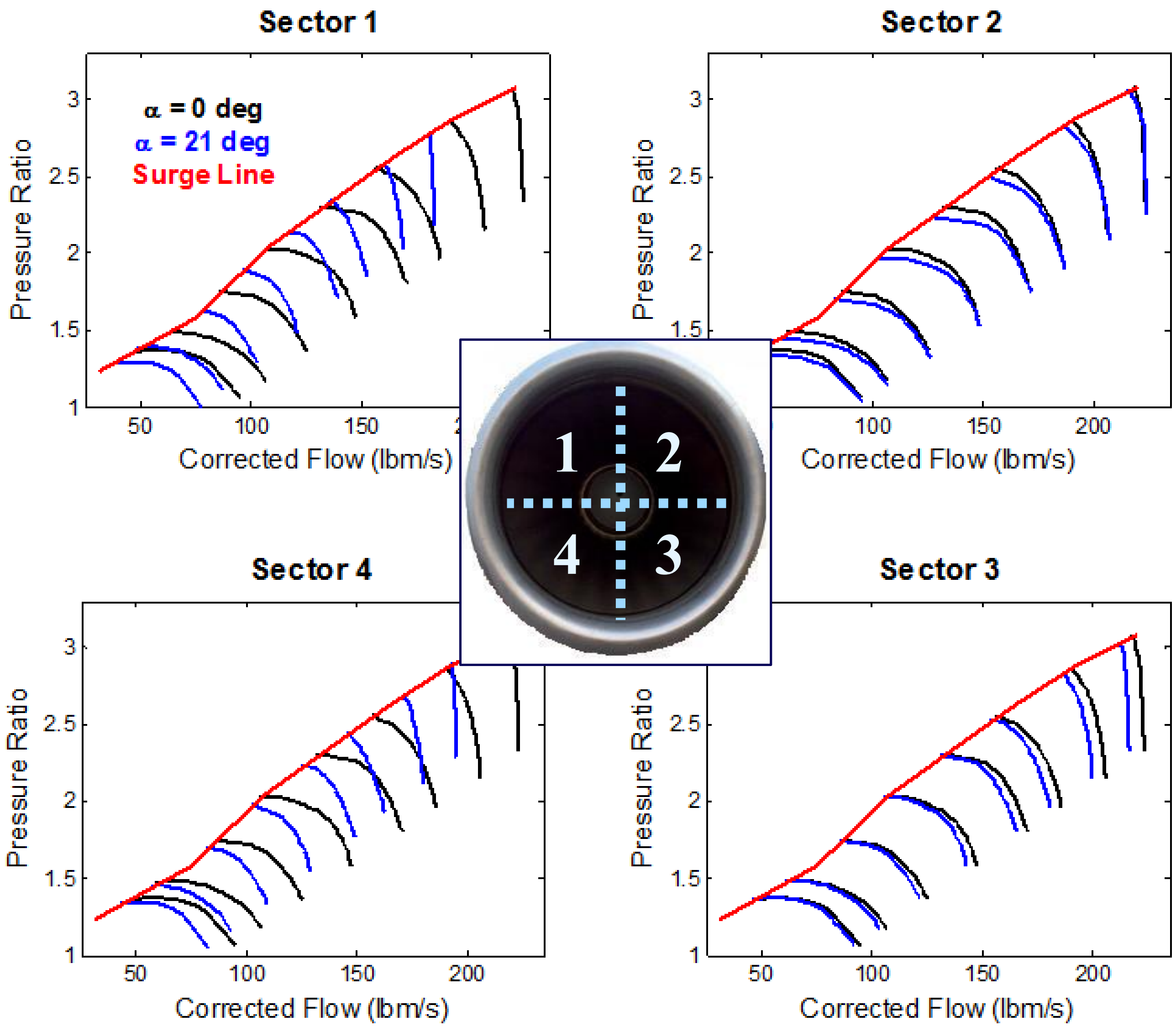
$$P_{out} = \frac{1}{6} P_{out,1} + \frac{5}{6} P_{out,2}$$

$$W_{out} = W_1 + W_2$$

$$T_{out} = \frac{W_1}{W_{out}} T_{out,1} + \frac{W_2}{W_{out}} T_{out,2}$$

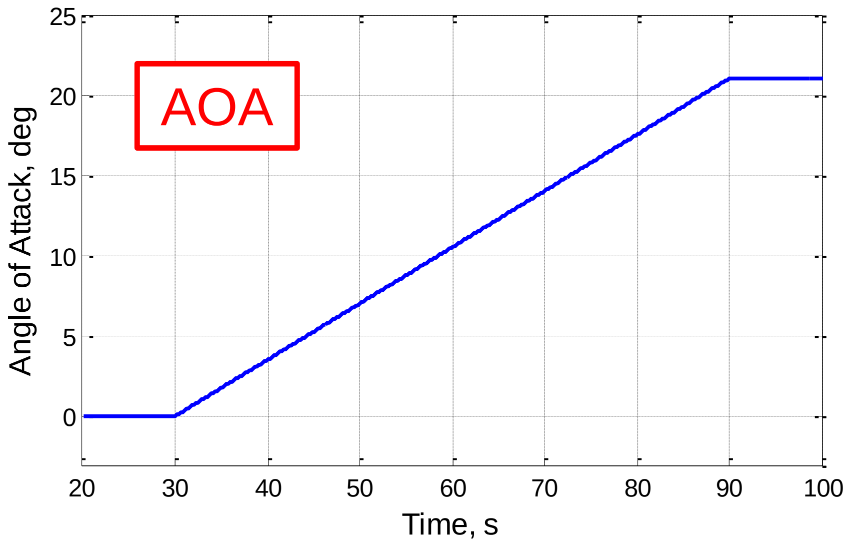
Engine Simulation: Parallel Compressor

- Fan divided into four equal parallel components
- Maps of each parallel compressor modified by scaling factors from CFD
- Uniform exit static pressure



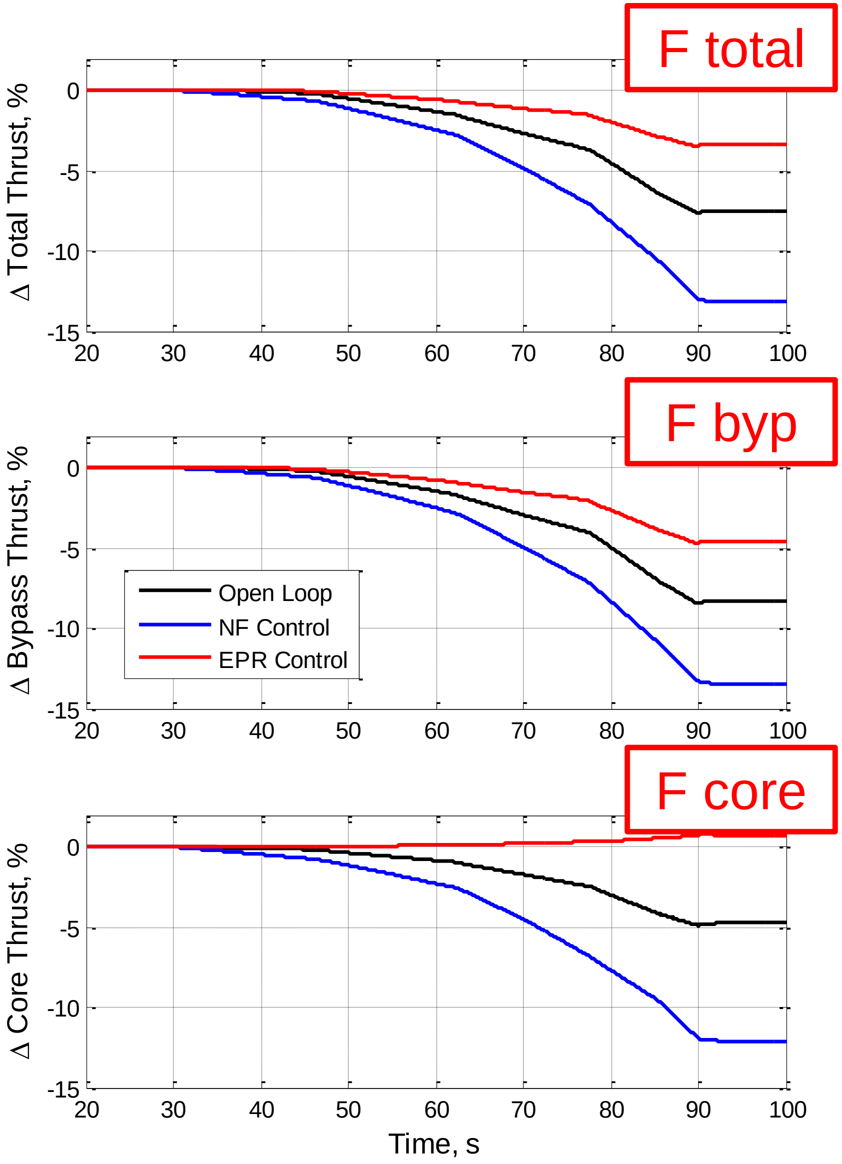
Results

- Increase AOA from 0 to 21 degrees (quasi-steady)
- Test cases:
  - Open-loop (OL): fuel flow held constant
  - Feedback control on fan speed (NF)
  - Feedback control on engine pressure ratio (EPR)



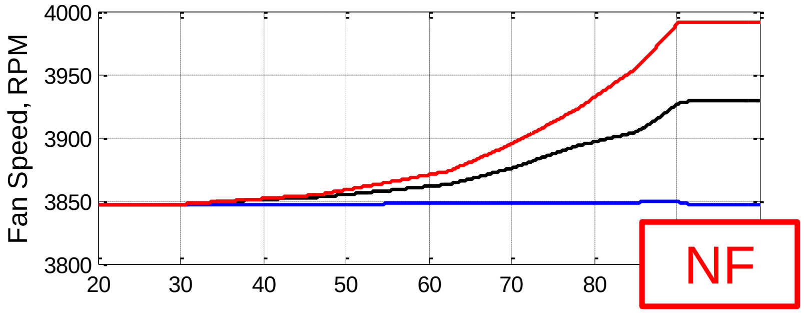
Results: Net Thrust

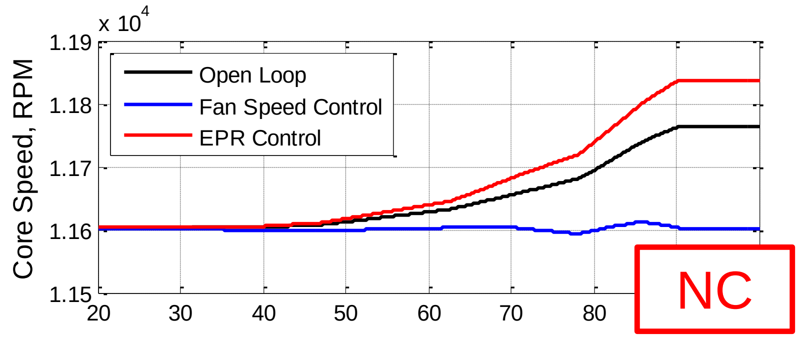
- Overall engine thrust decreases
- With higher AOA, fan performance decreases, fan thrust decreases
- Magnitude of thrust loss dependent on control parameter

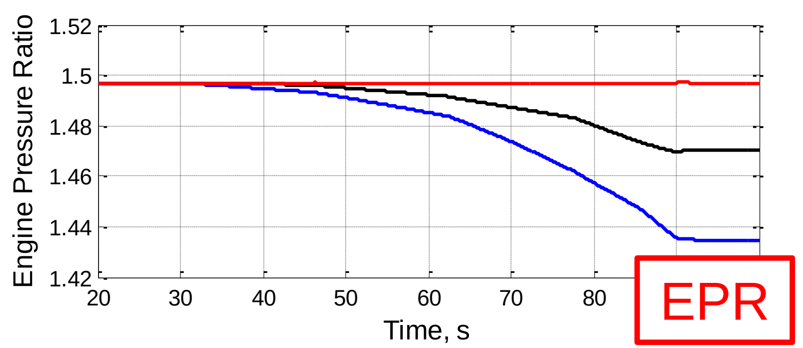


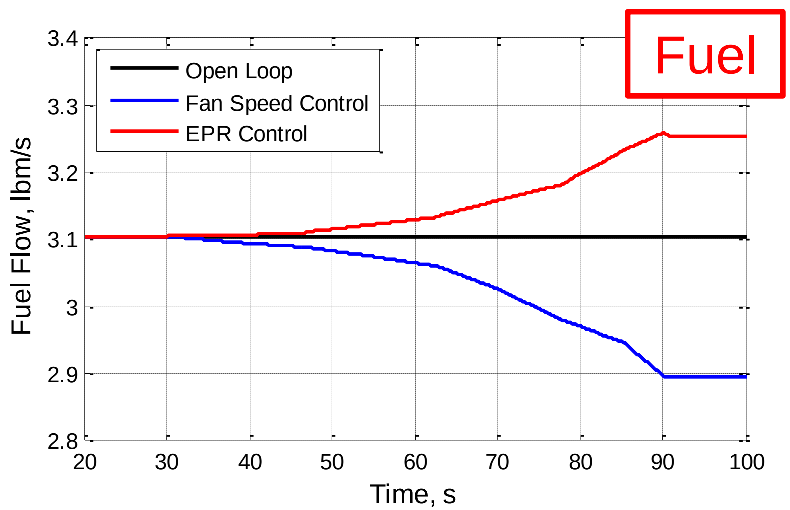
Results: Control Parameters

- Degraded fan performance
  - Lower pressure rise
  - Less power required to maintain given fan speed
- OL: fan speed rises due to positive power imbalance on LP spool
- NF: cut fuel to maintain NF
- EPR: add fuel to increase pressure rise across fan to maintain EPR









Summary & Future Work

- Simulation of commercial aircraft-type fan/inlet at high AOA via 3D CFD
- Incorporation of CFD results into lower-fidelity turbofan model via parallel compressor theory
- Engine performance assessment must take into account engine control system
- Future work:
  - Full-annulus simulation of fan and inlet
  - Characterization of flow dynamics

References

- Liu, Yuan, Claus, Russell W., Litt, Jonathan S., Guo, Ten-Huei, "Simulating Effects of High Angle of Attack on Turbofan Engine Performance," AIAA 2013-1075, 51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Grapevine, TX, January 7-10, 2013, also NASA/TM—2013-217846, February 2013.